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### (54) Multi-valve fluid flow control system and method

(57) A system and method for controlling production fluid flow from a chamber (10b) extending between a casing (6) disposed in a downhole bore and tubing (14) disposed in the casing (6). A plurality of valves (12) are disposed in respective openings formed in the tubing, and a passage (12a) is formed in each valve (12) for connecting the chamber (10b) and the tubing interior. The valves (12) are selectively closed to prevent any fluid flow through the passage (12a), and selectively opened to permit fluid flow from the chamber (10b), through the passage (12a), and into the interior of the tubing (14). Thus, the volume of fluid passing from the chamber (10b), through the valve members, and to the interior of the tubing is controlled.

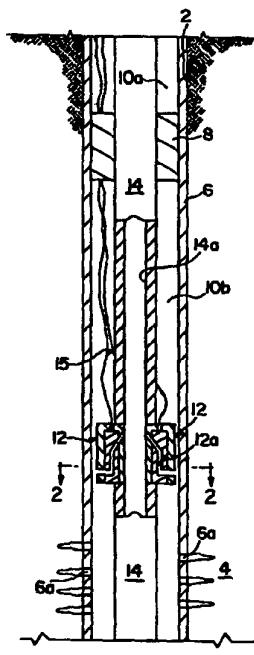


FIG. 1

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**Description**

[0001] This invention relates generally to a control system and method for controlling the flow of oil and gas from a well bore casing to a production tubing and, more particularly, to such a system and method utilizing a plurality of valves for controlling the oil and gas flow.

[0002] In oil production installations, a well bore annulus, or casing, lines the well bore. Oil and gas (hereinafter "production fluid") present in an underground oil reservoir flows into the casing through perforations in the casing. Production tubing for transporting the production fluid from the reservoir level is disposed in the casing and extends upwards to the ground surface.

[0003] A valve is often used to control production fluid flow from inside the casing to the production tubing. One type of conventional valve uses a sliding sleeve valve, or choke, that utilizes a slotted sleeve which axially slides over a slotted port. However, a single choke valve does not allow for any incremental control of the production fluid flow. Furthermore, the linearly sliding choke occupies a relatively large space, which can be a major disadvantage since the casing interiors are relatively narrow, thus requiring greater valve lengths, and thus more material to manufacture the valve.

[0004] Another valve design uses an electro-hydraulic control system to open or close a valve, and a solenoid to control a hydraulic line. However, this design also does not allow for incremental production fluid flow control, utilizes a relatively large amount of electrical power, and is also relatively bulky.

[0005] Therefore, what is needed is a system of the above type that provides incremental control over the fluid flow, yet is simple, inexpensive, and relatively small in size.

[0006] Therefore the system and method according to an embodiment of the present invention controls production fluid flow from a chamber extending between a casing disposed in a downhole bore and tubing disposed in the casing. A plurality of valves are disposed in respective openings formed in the tubing, and a passage is formed in each valve for connecting the chamber and the tubing interior. The valves are selectively closed to prevent any fluid flow through the passage, and selectively opened to permit fluid flow from the chamber, through the passage, and into the interior of the tubing. Thus, the volume of fluid passing from the chamber, through the valve members, and to the interior of the tubing is controlled.

[0007] The system of the above embodiment provides incremental control over the amount of fluid flow, yet is simple, inexpensive, and relatively small in size, while requiring minimal electrical power.

[0008] According to another aspect of the invention there is provided a production fluid control system comprising a casing disposed in a downhole bore for receiving production fluid; tubing disposed in the casing with

the outer surface of the tubing spaced from the inner surface of the casing to define an annular chamber for receiving the production fluid, the tubing having a plurality of openings formed in its walls; a plurality of valves respectively extending in the openings, each valve having a passage extending therethrough and communicating with the chamber and the interior of the tubing, each valve comprising a valve member movable between a closed position relative to the passage to prevent any fluid flow through the passage and an open position to permit fluid flow from the chamber, through the passage, and into the interior of the tubing; and a controller for selectively moving the valve members to and from their open and closed position to control the amount of fluid passing from the chamber, through the valve members, and to the interior of the tubing.

[0009] In an embodiment, the controller opens all of the valves to permit maximum flow of the fluid, and closes all of the valves to prevent any flow of the fluid. The controller may sense the volume of the production fluid and selectively moves the valve members their open position and to their closed positions to control the amount of fluid flow accordingly.

[0010] In an embodiment, the system further comprises a electrically-actuated solenoid associated with each valve member for moving it between its open and closed position, and wherein the controller sends electrical signals to the solenoids to selectively open and close the valves.

[0011] In an embodiment, the valves are angularly spaced around the tubing. The valves may also be axially spaced along the tubing.

[0012] According to another aspect of the invention there is provided a method of controlling production fluid flow from a chamber extending between a casing disposed in a downhole bore and tubing disposed in the casing, comprising the steps of disposing a plurality of valves in respective openings formed in the tubing, connecting the chamber and the tubing interior with a passage formed through each of the valves, selectively closing the passages to prevent any fluid flow through the passage, and selectively opening the passages to permit fluid flow from the chamber, through the passage, and into the interior of the tubing to control the volume of fluid passing from the chamber, through the valve members, and to the interior of the tubing.

[0013] In an embodiment, all of the passages are opened to permit maximum flow of the fluid, and all of the passages are closed to prevent any flow of the fluid.

[0014] In an embodiment, the method further comprises the step of sensing the volume of the production fluid and selectively opening and closing the valves accordingly to control the amount of fluid flow.

[0015] In an embodiment, each of the valves is electrically operated and further comprising the step of providing electrical signals to selectively open and close the valves.

[0016] In an embodiment, the method further com-

prises the step of angularly spacing the valves around the tubing. The method may further comprise the step of axially spacing the valves along the tubing.

[0017] According to another aspect of the invention there is provided a production fluid control system comprising a casing disposed in a downhole bore for receiving production fluid; tubing disposed in the casing with the outer surface of the tubing spaced from the inner surface of the casing to define an annular chamber for receiving the production fluid, the tubing having a plurality of openings formed in its walls; a plurality of valves respectively extending in the openings, each valve having a passage extending therethrough and communicating with the chamber and the interior of the tubing, each valve comprising a body member defining the passage and a valve member movable between a closed position relative to the passage to prevent any fluid flow through the passage and an open position to permit fluid flow from the chamber, through the passage, and into the interior of the tubing, a retaining device for applying a force to the valve member to retain it in its open and closed position; and a control device for overcoming the force and moving the valve member from its open position to its closed position and from its closed position to its open position.

[0018] In an embodiment, the retaining device is a spring-loaded detente that is urged into engagement with the valve member in its open position and its closed position.

[0019] In an embodiment, the retaining device comprises a flange disposed in a chamber in the body member and means for supplying hydraulic fluid to the chamber for forcing the flange, and therefore the valve member, to its closed position.

[0020] In an embodiment, the retaining device comprises another flange disposed in another chamber in the body member, and means for supplying hydraulic fluid to the latter chamber for forcing the other flange, and therefore the valve member to its open position.

[0021] In an embodiment, the control device comprises an electrically actuated solenoid that overcomes the force and moves the valve member between its open and closed positions. The control device may further comprise a controller to selectively apply electrical signals to the solenoids to selectively open and close the valve members. The controller may control the opening and closing of the valve members to control the amount of the fluid flow from the chamber to the interior of the tubing.

[0022] In an embodiment, the system further comprises means for compensating for fluid pressure variations occurring in the body member in response to the valve member moving to its open and to its closed positions.

[0023] According to another aspect of the invention there is provided a method of controlling production fluid flow from a chamber extending between a casing disposed in a downhole bore and tubing disposed in the

5 casing, comprising the steps of disposing a plurality of valves in respective openings formed in the tubing, connecting the chamber and the tubing interior with a passage formed through each of the valves, providing valve members for the passages for selectively closing the passages to prevent any fluid flow through the passage, and opening the passages to permit fluid flow from the chamber, through the passage, and into the interior of the tubing, applying a force to each valve member to retain it in its open closed position, applying a force to each valve member to retain it in its closed position; and overcoming the first-mention force to enable the valve member to move from its open position to its closed position, and overcoming the second-mentioned force to enable the valve member to move from its closed position to its open position.

[0024] In an embodiment, the first -mentioned force is applied by a spring-loaded detente that is urged into engagement with the valve member in its open position and its closed position.

[0025] In an embodiment, the second-mentioned force is applied by hydraulic fluid pressure acting on the valve member.

[0026] In an embodiment, the each step of overcoming comprises the step of connecting a solenoid to the valve member and actuating the solenoid to move the valve member to its open and closed positions. The step of actuating may be controlled to control the amount of the fluid flow from the chamber to the interior of the tubing.

[0027] In an embodiment, the method further comprises the step of compensating for fluid pressure variations occurring in the body member in response to the valve member moving to its open and to its closed positions.

[0028] According to another aspect of the invention there is provided a production fluid control system comprising a casing disposed in a downhole bore for receiving production fluid; tubing disposed in the casing with the outer surface of the tubing spaced from the inner surface of the casing to define an annular chamber for receiving the production fluid, the tubing having a plurality of openings formed in its walls; a plurality of valves respectively extending in the openings, each valve comprising a body member defining a passage, and a valve member defining a passage, and means for providing for relative rotation between the body member and the valve member to move the passages into alignment to permit fluid flow from the chamber, through the passages, and into the interior of the tubing, and to move the passages out of alignment to prevent any fluid flow.

[0029] In an embodiment, the degree of alignment of the passages can be varied to vary the amount of fluid flow.

[0030] According to another aspect of the invention there is provided a method of controlling production fluid flow from a chamber extending between a casing disposed in a downhole bore and tubing disposed in the

casing, comprising the steps of disposing a plurality of housings in respective openings formed in the tubing, connecting the chamber and the tubing interior with a passage formed through each of the housing, providing a valve member in each housing, providing a passage through each valve member, and providing for relative rotation between the housing and its corresponding valve member to align their respective passages to permit fluid flow from the chamber, through the passages, and into the interior of the tubing and to disalign their respective passage to prevent any fluid flow.

[0031] In an embodiment, the system further comprises the step of varying the degree of alignment of the passages to vary the amount of fluid flow.

[0032] Reference is now made to the accompanying drawings, in which:

Fig. 1 is a sectional view of a downhole bore production fluid recovery system incorporating an embodiment of a multi-valve fluid control system according to the present invention;

Fig. 2 is a cross-sectional view taken along a line 2-2 of Fig. 1;

Fig. 3 is a perspective view, partially in section, depicting an alternative disposition of the valves of Figs. 1 and 2;

Fig. 4 is a schematic view of the multi-valve fluid flow control system;

Fig. 5 is a sectional view of a first embodiment of a valve of the system of Figs. 1-4;

Fig. 6 is a sectional view of a second embodiment of a valve of the system of Figs. 1-4;

Fig. 7 is a sectional view of a third embodiment of a valve of the system of Figs. 1-4; and

Fig. 8 is a perspective view of a valve member of the valve of the embodiment of Fig. 7.

[0033] Referring to Figs. 1 and 2, the reference numeral 2 refers to a borehole formed in the ground and penetrating an oil and gas reservoir 4. A cylindrical casing 6 lines the borehole 2, and multiple perforations 6a are formed in the casing to allow production fluid to flow from the reservoir 4 into the casing for removal to the surface in a manner to be described. A packer 8 is disposed within the casing 6 and partitions the space defined by the casing 6 into chambers 10a and 10b.

[0034] A plurality of valves 12 are disposed within the casing chamber 10b and are mounted on a section of production tubing 14 that extends from the surface to an area in the casing in the vicinity of the reservoir 4. To this end, a plurality of angularly-spaced slots are formed in the tubing 14 that respectively receive a portion of each valve 12. Each valve 12 has a passage 12a extending therethrough and communicating at one end with the chamber 10b and at the other end with the interior 14a of the tubing 14. A valve 12 will be described in detail later.

[0035] A flatpack 15, in the form of an umbilical,

extends from the surface, down the borehole 2 between the casing 6 and the tubing 14 and is connected to each valve 12. The flatpack 15 is connected to a controller (not shown) at the surface and contains electrical lines, hydraulic lines, and communication conductors for conducting signals from the controller to selectively open and close the valves to respectively permit and prevent the flow of fluid therethrough, in a manner to be described. In this context, each valve 12 can be opened and closed by the controller, via the flatpack 15, independently of the operation of the other valves in a manner to be described.

[0036] In operation, production fluid flows into the casing 6 through the multiple perforations 6a, and enters the casing chamber 10b. When a valve 12 is in its open position, it allows production fluid to flow from the casing chamber 10b, through the passage 12a in the valve, and to the interior 14a of the tubing 14 for passage through the tubing to the surface for recovery.

[0037] Referring to Fig. 3, an alternative arrangement of the valves 12 relative to the tubing 14 is shown. According to this arrangement the valves 12 are angularly and axially spaced relative to the tubing 14. Otherwise, the arrangement of Fig. 3 is identical to that of Figs. 1 and 2. This valve arrangement permits a relatively large number of valves to be utilized, and the individual valves 12 may be wider, and yet still fit within the relatively narrow confines of the casing 6.

[0038] Fig. 4 depicts a series of steps for controlling the volume of production fluid ("operating production fluid flow volume") delivered by the production tubing 14 to the surface using either the valve arrangement of Figs. 1 and 2 or that of Fig. 3. More particularly, the operating production fluid flow volume is initially determined in step 16 and, in step 18, the desired production fluid flow volume for maximizing the production from the reservoir 4 is determined. In step 20, the desired production fluid flow volume (determined in step 18) is attained by the above-mentioned controller logically opening or closing each of a series of eight valves, each of which is depicted by either an "O" (denoting that the valve is in the open position) or an "X" (denoting that the valve is in the closed position) extending horizontally in the step 20 box. For example, in the first alternate flow volume step 20a, all the valves are depicted as open ("O"). The operating production fluid flow volume may be incrementally adjusted by closing ("X") one valve 12, as in the step 20b. The system can further be incrementally adjusted by closing additional valves 12 to attain different flow volume steps 20c, 20d, 20e, 20f, 20g, 20h, until all the valves are closed as in step 20i, which represents zero flow volume.

[0039] A feedback loop 22 to step 16 allows for determination of the new operating production fluid flow volume and subsequent comparison between it and the desired production fluid flow volume from step 18, which may require the opening or closing of more of the valves 12.

[0040] It is thus seen that the system of the above embodiment provides incremental control over the amount of fluid flow, yet is simple, inexpensive, and relatively small in size, while requiring minimal electrical power.

[0041] The valve 12 shown on the right side of the tubing 14, as viewed in Fig. 1, is shown in detail in Fig. 5. The valve 12 includes a cylindrical housing 24, a portion of which is disposed in a corresponding opening formed in the wall of the tubing 14 (not shown in Fig. 5). The housing 24 has a radially extending inlet 24a formed in the lower portion thereof as viewed in Fig. 5, and a radially extending outlet 24b spaced from the inlet and formed through an diametrically-opposed wall of the housing.

[0042] An insert 26 is disposed in the housing 24, and is in the form of a solid cylindrical having various chambers and passages formed therethrough. More particularly, an axial bore 26a is formed in the lower portion of the housing with its lower end communicating with the inlet 24a. A passage 26b extends parallel to, and communicates with, the bore 26a. A radial bore 26c is also formed in the insert 26 and connects the bore 26a and the outlet 24b.

[0043] A nozzle 28 is removably disposed in the inlet 24a, and a screen 28a is disposed in the nozzle 28 to prevent particles of a predetermined size from entering the valve 12.

[0044] A piston 30 is slidably disposed in the insert 26 with a portion extending into the bore 26c. A tapered head 30a is disposed on one end of the piston 30, and a seat 32 is disposed in the insert 26 at the upper end of the bore 26a for receiving the head 30a of the piston. The valve 12 is in its closed position when the piston head 30a engages the seat 32, as shown, to prevent fluid flow through the bore 26a. The piston 30, and therefore the head 30a, are adapted to move upwardly to a spaced position from the seat 32 to permit fluid flow, under conditions to be described.

[0045] A bidirectional solenoid 34 is disposed in the insert 26 for controlling the movement of the piston 30 and extends between two chambers 36a and 36b which receive a pressure compensation fluid for reasons to be described.

[0046] A rod 38 extends from one end of the solenoid 34 and into the chamber 36a and is connected to the other end of the piston 30 by an adapter, or connector, 38a. A second rod 40 extends from the solenoid 34 in the opposite direction, through the chamber 36b and into an opening formed in the insert 26. The rod 40 has a pair of grooves, 40a and 40b, and is operably connected to the rod 38 in the interior of the solenoid 34.

[0047] A detente 42 is disposed in a radial opening in the insert 26 and is forced by a spring, or the like (not shown) radially inwardly into engagement with the grooves 40a and 40b of the rod 40. The detente 42 engages the groove 40b when the piston 30 is in its closed position as shown, and engages the groove 40a

when the piston is in its open position, as will be described.

[0048] A floating compensation piston 44 is slidably disposed in the insert 26 above the upper end of the rod 40. A seal ring 46 surrounds the piston 44 and engages the corresponding surface of the insert 26 to define two chambers 48a and 48b. The chamber 48a extends between the lower surface of the piston 44 and a solid portion of the insert 26 and is filled with pressure compensation fluid. Although not shown in the cross section of the drawings, it is understood that the chamber 48a communicates with chambers 36a and 36b to form a closed system. The chamber 48b communicates with the upper end of the passage 26b so that the fluid pressure at the inlet 24a is transferred through the bore 26a and the passage 26b, and to the chamber 48b.

[0049] The flatpack 15 (Fig. 1) electrically connects the above-mention controller on the surface to the solenoid 34 to transmit electrical signals from the controller to the solenoid to move the piston 30 between its opened and closed positions relative to the seat 32, as described above. When the groove 40b of the rod 40 is engaged by the detente 42 to retain the piston 30 in its closed position, the fluid pressure at the inlet 24a is relatively high and is transmitted, via the chamber 26b, to the chamber 48b. This, in turn, forces the piston 44 downwardly to cause a corresponding increase in the pressure of the compensation fluid in the chamber 48a and therefore in the chambers 36b and 36a, thus equalizing the forces on the piston 44.

[0050] The valve 12 is operated by a corresponding signal from the above-mentioned controller transmitted by the flatpack 15 (Fig. 1) to the solenoid 34 to activate the solenoid which functions to move the piston 30 upwardly as viewed in Fig. 1 so that the head 30a extends above the seat 32. When the piston 30 moves upwardly a predetermined distance, the detente 42 engages the groove 40a of the rod 40 and thus holds the piston 30 in the open position. Fluid thus flows from inlet 24a, through the bore 26a and the opening in the seat 32 and discharges from the bore 26c and the outlet 24b. The fluid pressure at the inlet 24a thus decreases, causing a corresponding decrease in the fluid pressure in the chamber 48b. Thus, the relatively high-pressure fluid in the chambers 48a, 36b, and 36a acts against the compensation piston 44 to force it upwardly as viewed in Fig. 5 and equalize the forces on the piston. The solenoid 34, when activated as described above, exerts a force sufficient to overcome the engagement of the groove 40a or 40b by the detente 42 when the solenoid is activated to move the piston 30 to a new selected position.

[0051] It is understood that many, if not all, of the above components, with the exception of the seal rings, can be constructed of an erosion-resistant material, such as tungsten carbide, to withstand the heat, pressure, and particles associated with reservoir depths.

[0052] There are several advantages to the above.

For example, the piston 30 is electrically driven by actuation of the solenoid 34, yet utilizes a hydraulic fluid assist to maintain the piston in its open and closed position. Also, the engagement of the detente 42 with either the groove 40a or 40b restrains the piston 30 in the selected position, and thereby reduces the electrical energy required by the solenoid 34 to keep the piston in the selected position. Further, the piston 44 functions to equalize pressure variations caused by the opening and closing the valve 12 and by temperature changes between the surface and the downhole location of the valve 12, thus decreasing the energy required by the solenoid 34 to move the piston 30. Also, the nozzle 28 can be replaced with a nozzle having a different inlet diameter to further adjust the production fluid flow volume and pressure accordingly.

[0053] Fig. 6 depicts an alternative embodiment of the valve 12, generally referred to by the reference numeral 12' which is located in the tubing 14 in the same manner as the valve 12. The valve 12' includes a cylindrical housing 49 having a radially extending inlet 49a communicating with the chamber 10b and a radially extending outlet 49b spaced from the inlet and communicating with interior 14a of the tubing 14.

[0054] An insert 50 is disposed in the housing 49, and has a stepped axial bore 50a formed in the lower portion thereof as viewed in Fig. 6 and in communication with the inlet 49a. A passage 50b is formed in the insert 50 and extends parallel to, but isolated from, the bore 50a, as will be explained. The insert 50 also has a radial bore 50c which connects the bore 50a and the housing outlet 49b.

[0055] A nozzle 52 is removably disposed in the inlet 49a, and a screen 52a, is disposed in the opening of the nozzle 52 to prevent particles of a predetermined size from entering the valve 12'.

[0056] A piston 54 is slidably disposed in the insert 50 with a portion extending into the bore 50c. A tapered head 54a is disposed on one end of the piston, and a seat 56 is disposed in the insert 50 at the other end of the bore 50a for receiving the head 54a of the piston. The valve 12' is in its closed position when the piston head 54a engages the seat 56 to prevent fluid flow through the bore 50a. The piston 54, and therefore the head 54a, are adapted to move upwardly, as viewed in Fig. 6 to an open position in which the head is spaced from the seat 56, as shown, to permit fluid flow, under conditions to be described.

[0057] A bidirectional solenoid 58 is provided for controlling the movement of the piston 54 and is disposed between two chambers 60a and 60b. Both chambers 60a and 60b receive a pressure compensation fluid, and the chamber 60b is connected to the passage 50b, as will be explained.

[0058] A rod 62 extends from the lower end of the solenoid 58 as viewed in Fig. 6, into the chamber 60a, and is connected to the other end of the piston 54 by a connector, or adapter 62a.

[0059] A hydraulic piston 64 is slidably disposed in the insert 50 above the upper end of the solenoid 58, and has a circular flange 64a formed thereon which engages the corresponding surface of the insert 50, via a sealing ring 65a, to define the chamber 60b between it and the upper surface of the solenoid. The lower end of the piston 64 is operably connected to the rod 62 in the interior of the solenoid 58, and therefore to the piston 54.

5 [0060] A chamber 66a is defined between the upper surface of the flange 64a and a corresponding surface of the insert 50. The chamber 66a communicates with a hydraulic passage 68a formed in the insert 50 which receives hydraulic fluid from a line included in the flatpack 15 (Fig. 1) and passes the fluid to the chamber 66a.

10 [0061] An additional circular flange 64b is formed on the piston 64 in a spaced relation to the flange 64a. That portion of the piston 64 extending between the flanges 64a and 64b slides in a corresponding opening in the insert 50 with a ring seal 65b disposed therebetween. The outer surface of the flange 64b engages a corresponding surface of the insert 50 defining the chamber 66b, via a sealing ring 65c. The chamber 66b is connected to a hydraulic passage 68b which receives hydraulic fluid from a line included in the flatpack 15 (Fig. 1) and passes the fluid to the chamber 66b.

15 [0062] A pressure compensation piston 70 is slidably mounted in the lower portion of the bore 50a. An O-ring 72 surrounds the piston 70, and engages the corresponding surface of the bore 50a, to partition the bore into chambers 74 and 76. The chamber 74 contains a pressure compensation fluid and is connected to the chambers 60a and 60b by a passage 50b to form a closed system. The chamber 76 communicates with the inlet 49a and thus receives the production fluid pressure at the inlet.

20 [0063] To open the valve 12', the solenoid 58 is actuated to move the piston 54 to its open position in which the head 54a of the piston is spaced from the seat 56 as shown in Fig. 6. Also, the hydraulic line associated with the passage 68b is actuated so that hydraulic fluid passes into, and builds up in, the chamber 66b to apply an upwardly-directed force on the flange 64b and the piston 64, and therefore the piston 54, to maintain it in its open position. Production fluid flows from the casting chamber 10b through the nozzle 52 and the inlet 49a, in a direction indicated by the reference arrow A. The fluid flows through the seat 56, past the piston 54, through the bore 50c, and out of the outlet 49b to the interior of the tubing 14a for passing through the tubing 14 to the surface. The inlet pressure in chamber 76 decreases, allowing the compensation production fluid pressure in the chambers 74, 60b, and 60a to act against the piston 70, which moves accordingly to equalize the compensation pressure with the inlet pressure.

25 [0064] The valve 12' is closed in response to a sig-

nal generated at the controller and carried by the flatpack 15 from the controller to the solenoid. When this occurs, the solenoid 58 urges the rod 62, and therefore the piston 54, downwardly as viewed in Fig. 6, until the head 54a engages seat 56, thus closing the valve 12'. The hydraulic line carried in the flatpack 15 and associated with the passage 68a is actuated so that hydraulic fluid passes into, and builds up in, the chamber 66a to apply an downwardly-directed force on the flange 64a and the piston 64, and therefore the piston 54, to maintain it in its closed position.

[0065] This downward movement of the flange 64a thus reduces the volume of chamber 60b, thereby increasing the pressure throughout the compensation chambers 60a, 60b, and 74 which would normally result in upward movement of the compensation piston 70. However this pressure increase of the compensation fluid is counteracted by the inlet pressure, which increases in response to the closing of the piston 54 with the seat 56. Thus, the embodiment of Fig. 6 enjoys all the advantages of the embodiment of Fig. 5 while utilizing alternative designs to provide the hydraulic assist and to equalize the pressure variations caused by the opening and closing of the valve 12 and by temperature changes between the surface and the downhole location of the valve 12.

[0066] Referring to Figs. 7 and 8, another alternative embodiment of the valve is generally referred to by the reference numeral 12" which would be located in the tubing 14 in the same manner as the valves 12 and 12'. The valve 12" includes a cylindrical housing 78 having an axial bore 78a extending for substantially the entire length thereof, and an axial bore 78b in the upper portion of the housing 78 as viewed in Fig. 7 which has a relatively small diameter and which is tapered outwardly to communicate with the first axial bore 78a. A slot 78c extends radially through a wall of the housing 78 in communication with the casing chamber 10b, and a slot 78d extends through an opposed wall portion of the housing 78 in communication with the interior 14a of the tubing 14.

[0067] A tubular valve member 80 is disposed in the axial bore 78a of the housing 78 and has a through slot 80a, which extends radially through the member. The housing 78 is rotatable relative to the valve member 80 so that, when the slots 78c and 78d of the housing align with the slot 80a of the valve member 80, production fluid can flow from the casing chamber 10b to the interior of the tubing 14 with the amount of fluid flow depending on the degree of alignment of the slots, as well as the number of open valves.

[0068] The valve member 80 has a first axial bore 80b extending through a portion of the length thereof extending below the slot 80a. Another axial bore 80c is provided in the lower end portion of the valve member 80 and has a first portion of a larger diameter than that of the bore 80b and an inwardly-tapered portion which communicates with the latter bore.

5 [0069] As shown in Fig. 7, four axially-spaced seal rings 82a, 82b, 82c, and 82d extend in annular grooves formed in the outer surface of the valve member 80 and respectively engage corresponding surfaces of that portion of the housing 78 defining the bore 78a, to provide a fluid seal.

10 [0070] It is understood that the housing 78 is rotatable relative to the valve member 80 in any known manner such as by a rotating solenoid or a direct current (DC) brush-less motor that is operatively connected to the housing.

15 [0071] In operation, and assuming that the valve member 80 is in its closed position in which the slot 80a is not aligned with the slots 78c and 78d of the housing 78, thus blocking the flow of the production fluid through the valve 12", the aforementioned solenoid is actuated in response to a signal carried by the flatpack 15 (Fig. 1) from the above-mentioned controller (not shown). The solenoid functions to rotate the above-mentioned housing 78 until the housing slots 78c and 78d align with the slot 80a of the valve member 80 as shown in Fig. 7. Production fluid thus can flow from the casing chamber 10b through the aligned slots 78c, 80a and 78d and into the interior 14a of the tubing 14 for flow to the surface. It is noted that the amount of fluid flow through the valve 12" can be regulated by varying the degree of alignment of the slots 78d and 78d with the slot 80a.

20 [0072] If it is desired to close the valve 12" the solenoid is actuated again thus causing the housing 78 to rotate until the slot 78c and 78d move out of alignment with the slot 80a thus preventing the flow of the production fluid through the valve.

25 [0073] It is understood that production fluid or hydraulic fluid from a line included in the flatpack 15 could be introduced into the bore 78b and/or the bore 80c to minimize any pressure drop across the valve member 80 to maintain its axial alignment relative to the housing 78.

30 [0074] An advantage of the embodiment of Figs. 7 and 8 is that the overall size of the valve 12" is reduced. Also, the production fluid flow can be controlled and varied in smaller increments, thus optimizing the reservoir production fluid output.

35 [0075] It is understood that, according to an alternative arrangement of the embodiment of Figs. 7 and 8 the valve member 80 can be rotatable relative to the housing 78. In this case, a stem, or the like (not shown) would extend from one of the ends of the valve member 80 and through the bore 78b or the bores 80b and 80c and would be operatively connected to a corresponding solenoid or motor to rotate the stem, and therefore the valve member 80.

40 [0076] It is also understood that variations may be made to the foregoing without departing from the scope of the invention. For example, although reference is made to "lines" and "tubing" it is understood that conduits, pipes, hoses and any other type of fluid flow device could be used within the scope of the invention.

Also, the spatial references, such as "upper" and "lower", "axial", "radial", etc. are for the purpose of illustration only and do not limit the specific orientation or location of the structure described above. Still further, the system and method of the present invention are not limited to a production fluid controlling system but are equally applicable to any fluid flow system.

[0077] It is understood that other variations, changes and substitutions are intended in the foregoing disclosure and in some instances some features of the invention will be employed without a corresponding use of other features. Thus, the invention described above may be modified.

**Claims**

1. A production fluid control system comprising a casing disposed in a downhole bore for receiving production fluid; tubing disposed in the casing with the outer surface of the tubing spaced from the inner surface of the casing to define an annular chamber for receiving the production fluid, the tubing having a plurality of openings formed in its walls; a plurality of valves respectively extending in the openings, each valve having a passage extending therethrough and communicating with the chamber and the interior of the tubing, each valve comprising a valve member movable between a closed position relative to the passage to prevent any fluid flow through the passage and an open position to permit fluid flow from the chamber, through the passage, and into the interior of the tubing; and a controller for selectively moving the valve members to and from their open and closed position to control the amount of fluid passing from the chamber, through the valve members, and to the interior of the tubing.
2. A system according to claim 1, wherein the controller opens all of the valves to permit maximum flow of the fluid, and closes all of the valves to prevent any flow of the fluid.
3. A method of controlling production fluid flow from a chamber extending between a casing disposed in a downhole bore and tubing disposed in the casing, comprising the steps of disposing a plurality of valves in respective openings formed in the tubing, connecting the chamber and the tubing interior with a passage formed through each of the valves, selectively closing the passages to prevent any fluid flow through the passage, and selectively opening the passages to permit fluid flow from the chamber, through the passage, and into the interior of the tubing to control the volume of fluid passing from the chamber, through the valve members, and to the interior of the tubing.
4. A production fluid control system comprising a cas-

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ing disposed in a downhole bore for receiving production fluid; tubing disposed in the casing with the outer surface of the tubing spaced from the inner surface of the casing to define an annular chamber for receiving the production fluid, the tubing having a plurality of openings formed in its walls; a plurality of valves respectively extending in the openings, each valve having a passage extending therethrough and communicating with the chamber and the interior of the tubing, each valve comprising a body member defining the passage and a valve member movable between a closed position relative to the passage to prevent any fluid flow through the passage and an open position to permit fluid flow from the chamber, through the passage, and into the interior of the tubing, a retaining device for applying a force to the valve member to retain it in its open and closed position; and a control device for overcoming the force and moving the valve member from its open position to its closed position and from its closed position to its open position.

5. A system according to claim 4, wherein the retaining device comprises a flange disposed in a chamber in the body member and means for supplying hydraulic fluid to the chamber for forcing the flange, and therefore the valve member, to its closed position.
6. A system according to claim 4 or 5, wherein the control device comprises an electrically actuated solenoid that overcomes the force and moves the valve member between its open and closed positions.
7. A method of controlling production fluid flow from a chamber extending between a casing disposed in a downhole bore and tubing disposed in the casing, comprising the steps of disposing a plurality of valves in respective openings formed in the tubing, connecting the chamber and the tubing interior with a passage formed through each of the valves, providing valve members for the passages for selectively closing the passages to prevent any fluid flow through the passage, and opening the passages to permit fluid flow from the chamber, through the passage, and into the interior of the tubing, applying a force to each valve member to retain it in its open closed position, applying a force to each valve member to retain it in its closed position; and overcoming the first-mention force to enable the valve member to move from its open position to its closed position, and overcoming the second-mentioned force to enable the valve member to move from its closed position to its open position.
8. A method according to claim 8, wherein the each step of overcoming comprises the step of connect-

ing a solenoid to the valve member and actuating the solenoid to move the valve member to its open and closed positions.

9. A production fluid control system comprising a casing disposed in a downhole bore for receiving production fluid; tubing disposed in the casing with the outer surface of the tubing spaced from the inner surface of the casing to define an annular chamber for receiving the production fluid, the tubing having a plurality of openings formed in its walls; a plurality of valves respectively extending in the openings, each valve comprising a body member defining a passage, and a valve member defining a passage, and means for providing for relative rotation between the body member and the valve member to move the passages into alignment to permit fluid flow from the chamber, through the passages, and into the interior of the tubing, and to move the passages out of alignment to prevent any fluid flow. 5 10 15 20

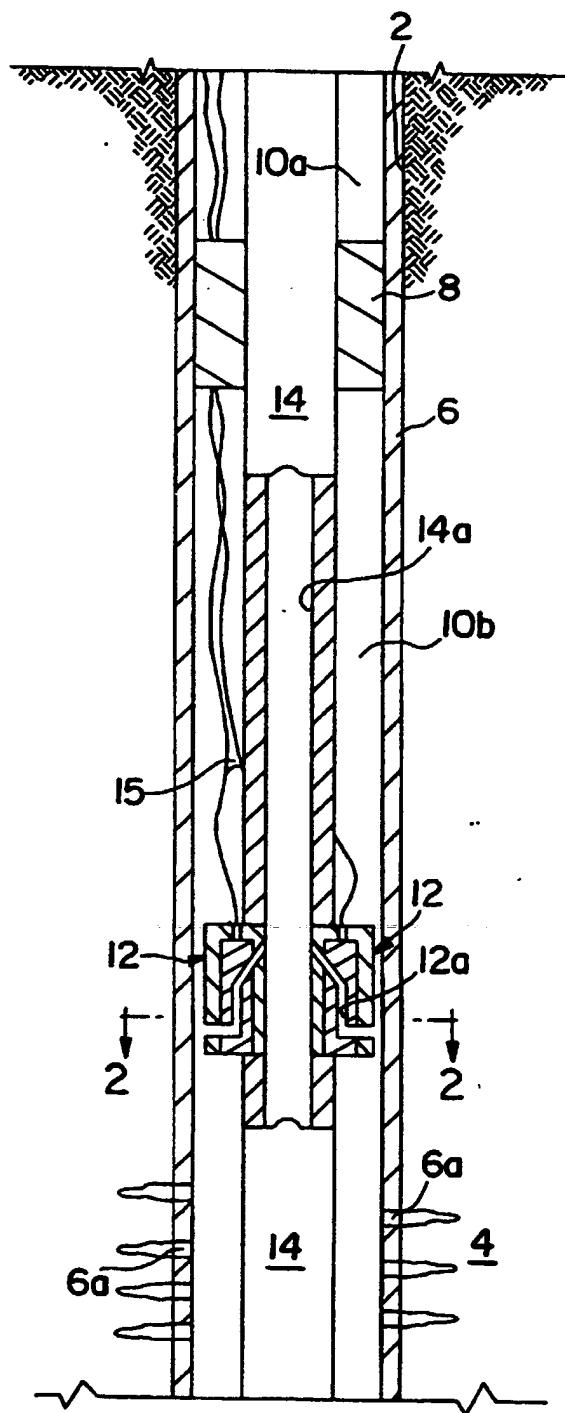
10. A method of controlling production fluid flow from a chamber extending between a casing disposed in a downhole bore and tubing disposed in the casing, comprising the steps of disposing a plurality of housings in respective openings formed in the tubing, connecting the chamber and the tubing interior with a passage formed through each of the housing, providing a valve member in each housing, providing a passage through each valve member, and providing for relative rotation between the housing and its corresponding valve member to align their respective passages to permit fluid flow from the chamber, through the passages, and into the interior of the tubing and to disalign their respective passage to prevent any fluid flow. 25 30 35

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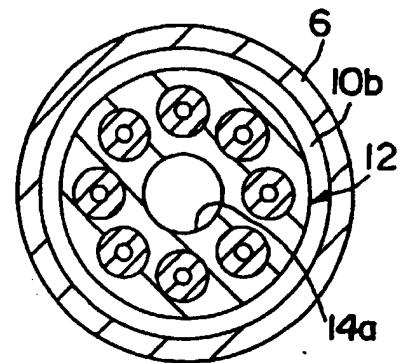
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## FIG. I



## FIG. 2

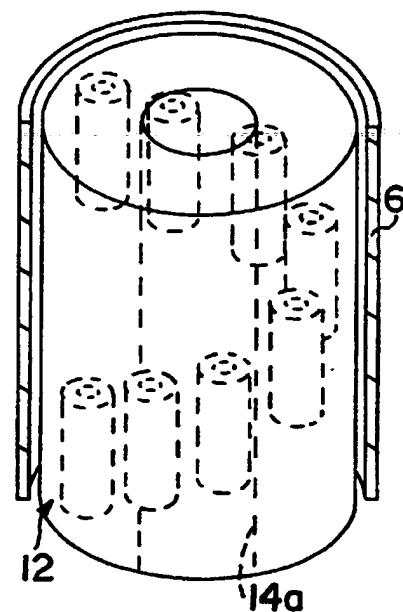


FIG. 3

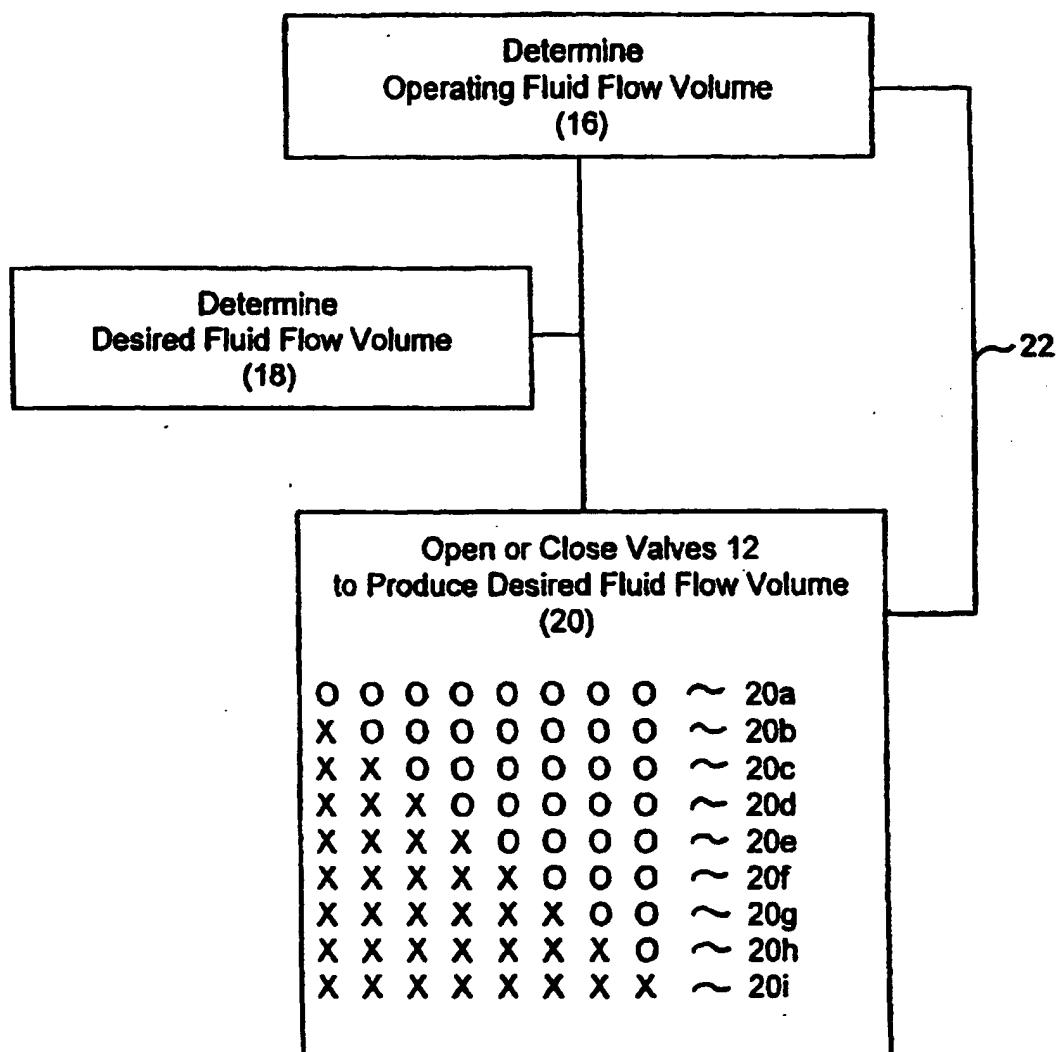


FIG. 4

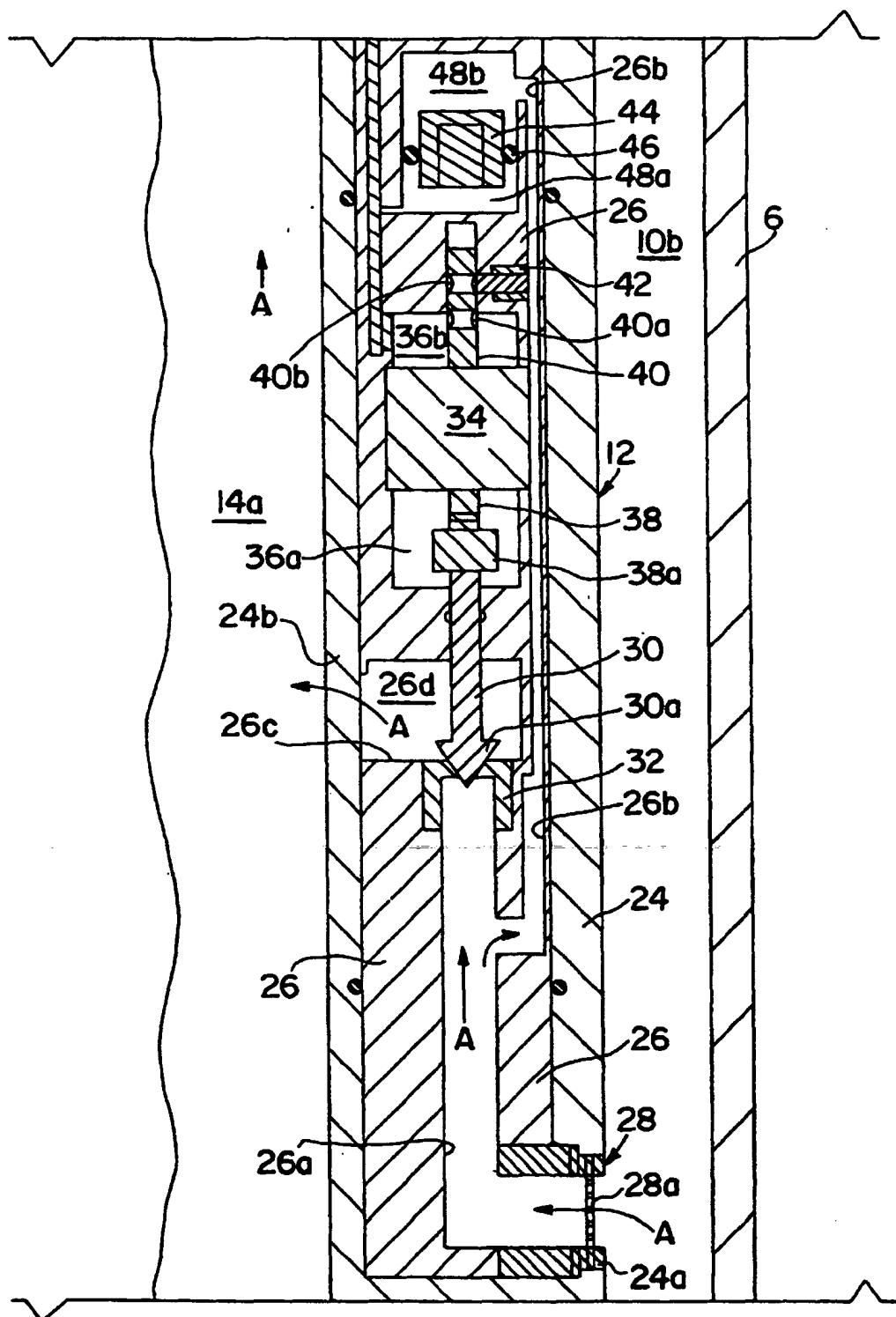
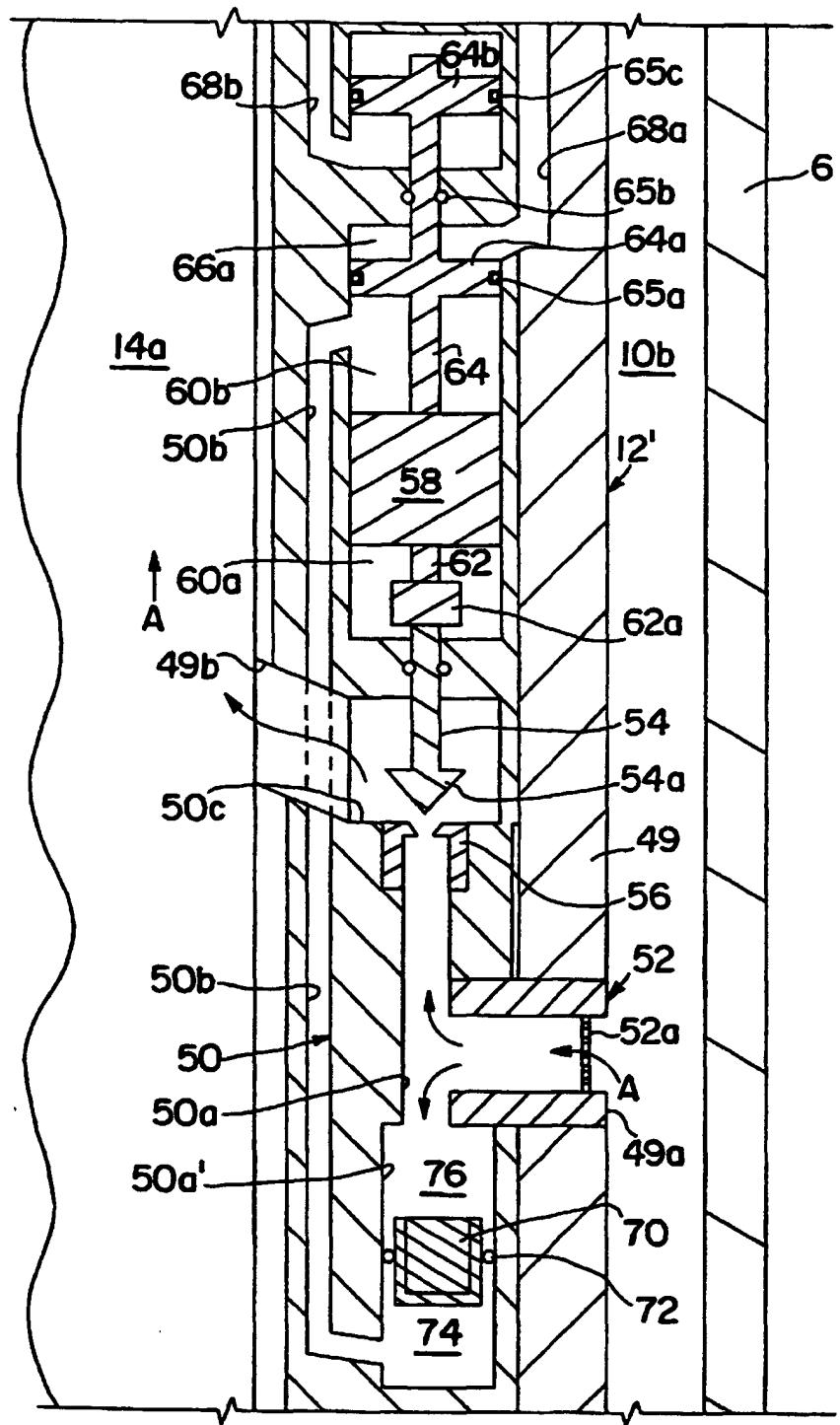
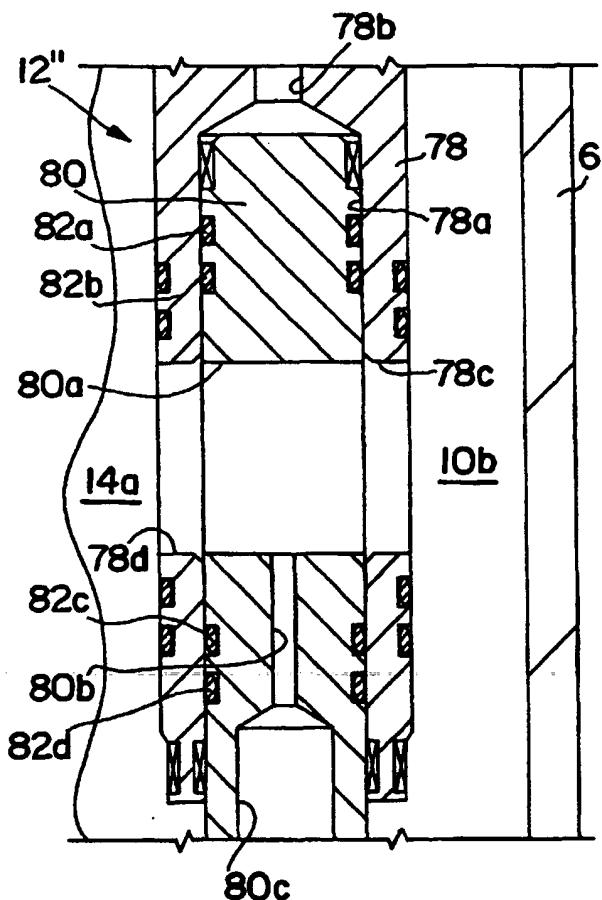
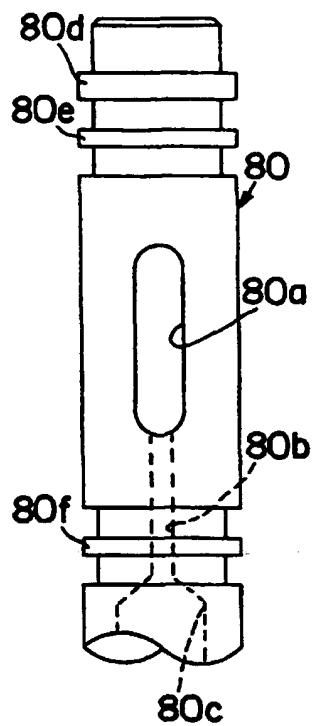


FIG. 5







European Patent  
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## EUROPEAN SEARCH REPORT

Application Number

EP 00 30 0020

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.)
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E21B			
<p>The present search report has been drawn up for all claims</p>			
Place of search  EPO FORM 1503 (03-82) (P04C01)	Date of completion of the search	Examiner	
THE HAGUE	10 March 2000	Garrido Garcia, M	
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ON EUROPEAN PATENT APPLICATION NO.

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10-03-2000

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